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AGRICULTURAL SCHOLARSHIPS

Management Techniques for Increasing Plant & Nutrient Efficiency to Improve Food Production

Daryl Chubb

November 2015

NUFFIELD CANADA

Nuffield Canada Agricultural Scholarships

Nuffield Canada offers scholarships to agricultural leaders to expand their knowledge and network with top individuals around the world, to promote advancement and leadership in agriculture.

As part of the larger international Nuffield community which includes the United Kingdom, The Republic of Ireland, Australia, New Zealand and Zimbabwe, scholarship recipients become a member of the over 1,500 strong Nuffield alumni which interact to aid the latest scholars and continue the development of past scholars.

Scholarships are available to anyone between the ages of 25 and 45 involved in agriculture in any capacity of primary production, industry or governance.

The scholarship provides individuals with the unique opportunity to:

1. Access the world's best in food and farming
2. Stand back from their day-to-day occupation and study a topic of real interest
3. Achieve personal development through travel and study
4. Deliver long-term benefits to Canadian farmers and growers, and to the industry as a whole

Applications are due annually by April 30th

SCHOLAR PROFILE

I grew up on a grain and cattle farm in central Saskatchewan, Canada. I developed a passion for agriculture early in life, which has now coupled with an entrepreneurial spirit. After completing my Bachelor of Science at the University of Saskatchewan, I worked in the grain purchasing and crop input sectors, and managed a major cropping enterprise business. Most recently, I started my own agriculture consulting firm, DeNovo Ag Inc., which offers fertility management, crop production planning, precision agriculture services, and cost of production analysis to farmers in the prairies of Western Canada.

When I applied for the Canadian Nuffield Scholarship, I was hoping for an experience that I could not get anywhere else. My expectations were far exceeded; the Nuffield Scholarship has provided me with an expanded personal and professional view of life and agriculture. I have also learned that the goals and challenges of agriculture are similar, no matter which part of the world I travelled to.

As a Nuffield Scholar, my initial focus was primarily on grain production. I wanted to investigate how we in Western Canada could produce better yields while capturing more of our fertility investment. Not far into my study, I realised that soil needed to be a primary focus in order to increase yields. Instead of focusing on a monoculture system, I found myself concentrating on polycultures and how different strategies such as incorporating livestock, multispecies cropping, and diversification at the farm level can improve our soils.

Figure 1. My visit to Rothamsted Research near Harpenden, United Kingdom (March 2015)

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my wife Karen for her support while I was travelling. Without her support and acceptance of the Nuffield life, this would not have been possible.

I would also like to thank Nuffield Canada for accepting me as a scholar and making this experience possible. The Nuffield connection opens so many doors and creates opportunities and relationships I would not have had otherwise.

Acknowledgment needs to be extended to Nuffield Australia, Jim Geltch, and his team for organizing the Global Focus Program and giving countless hours to organize the logistics for nine people who are travelling the globe.

I would like to thank my clientele for their support and patience during my travel and time away.

A special thank you to Steve Larocque for the introduction of Nuffield and introducing me to differences it can make.

I would also like to thank all the individuals that took time from their schedules to spend time with me, answer all my questions, provide transportation, lodging, countless conversations, and pass on their knowledge to me.

SPONSORSHIP

I would like to thank the following companies that found value investing in my Nuffield Scholarship:

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EXECUTIVE SUMMARY

2015 was declared "International Year of Soils" by Food and Agriculture Organization of the United Nations (FAO). Globally, soils are deteriorating because of erosion, nutrient depletion, loss of organic carbon, and other threats. Western Canada has some very good soils when compared globally. Cultivation began just over a century ago with practices that were adopted from Europe. Over the years our soils were prone to erosion due to intense cultivation. The loss of topsoil has dramatically reduced our organic matter (carbon) levels in our soils. Soil organic matter has a direct result in the quality of the soil, its production ability and its ability to support the living fraction of soil.

The primary focus of my report is to outline how new and different practices can be adapted into a farming system to improve soils, increase yields, and increase profit. I have seen many different production and conservation techniques used in Australia, Europe, United Kingdom, and North America. Farming businesses searching for suitable land for growing grain, vegetables, and fruit is competitive everywhere. The addition of stock and shifting towards a polyculture has allowed many to find the expansion in their business they were looking for.

A quote that followed me during my travels stated *"fertility will not increase production alone."* If we cannot rely on fertilizers to improve our production, how will the growing population have enough food to eat? It will be a combination of factors including:

- Intimate knowledge of the soil by utilizing different testing methods and incorporation of technology.
- Increasing the diversity of the business can be accomplished in a variety of ways including livestock, forages, legumes, broad cropping rotations and cover crops.
- The soil can physically be disturbed and redistributed to promote increasing soil quality.
- Increasing the efficiency of the fertility supplied chemically, organically or existing in the soil by
    - promoting the living fracture of the soil to flourish
    - promote the increase of soil organic matter
    - use of enhanced efficiency fertilizers
    - promote deep rooting of crops
    - limit compaction
    - use of plant growth regulators to manipulate the plants hormone production.
- Following the 4Rs of nutrient management.

DISCLAIMER

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1.0 INTRODUCTION

"The multiple roles of soils often go unnoticed. Soils don't have a voice, and few people speak out for them. They are our silent ally in food production" (José Graziano da Silva, FAO Director-General).

My study "Management Techniques for Increasing Plant & Nutrient Efficiency to Improve Food Production" initially, for me, was meant to find ways for our applied fertilizers to become more efficient to increase yield in field crops. I was hoping to find different fertilizers, additives or application methods that are different than what we currently use in Western Canada for grain production. I did not find exactly what I was looking for but did uncover many more questions for every answer I found.

As an agriculture consultant focusing primarily on grain production until now, I realize that my thinking and strategies need to change. If I can provide information to primary producers and they start asking questions or change their production practices, this could help with the long-term survival of agriculture.

Farmers have always pushed for higher yields because that is how they are primarily paid. The recent adoption of no-till has improved efficiency, saves money, conserves moisture and reduces erosion, but we have become reliant on chemical weed control and chemical fertilizer to improve production. Knowing this, I wonder if we are neglecting our soils. Can we incorporate some traditional methods without sacrificing the success and profitability of the farm for future generations?

I will discuss different management and application techniques along with how incorporation of livestock and diversity can aid in the increased efficiency of fertilizer and the soil. My topic is relevant and timely because with an increasing world population comes an increasing need for food. How do we increase food production while our natural resources are being depleted and our prime food producing lands are disappearing because of urban sprawl and the changing environment?

2.0 Management Techniques for Increasing Plant & Nutrient Efficiency to Improve Food Production: It's A System

In Western Canada, the focus of many primary producers has switched from a mixed farm to a more specialized operation. Many have decreased or sold off their stock because of age, lack of labour, and poor profitability (to name a few). Many acres that were once used for grazing and forage production have been tilled and are now producing grain crops. There is a steady increase in high input crops such as corn and canola but yields are not increasing as fast as the population trend.

No-till practices have been widely adopted and are now considered normal practice. This a major shift for areas such as United Kingdom (UK), where the plough has been used for generations and people are reluctant to change. In Western Canada, our change was fuelled by need during the drought conditions of the 1980's and 1990's. Where moisture is adequate, the push to change is not as strong.

2.1 Understanding Your Soil

Soil is defined as "a mixture of minerals, organic matter, gases, liquids, and the countless organisms that together support life on Earth" (Wikipedia n.d.). Soil is comprised of solids, liquids, and gases that are structured into different layers (or horizons) while differing in characteristics and properties due to the parent material (Wikipedia n.d.).

The prairies of Western Canada offer a variety of soil zones ranging from brown to gray (see Figure 2). The major differences between each are annual precipitation, climate, and overall yield potential. The black soil zone typically has the greatest potential. Within these soil zones, there are many differing soils. I personally deal with some heavy clay soils that range from moderately alkaline to sandier and slightly acidic. This variation in soil in such a small geographic area requires many different strategies.

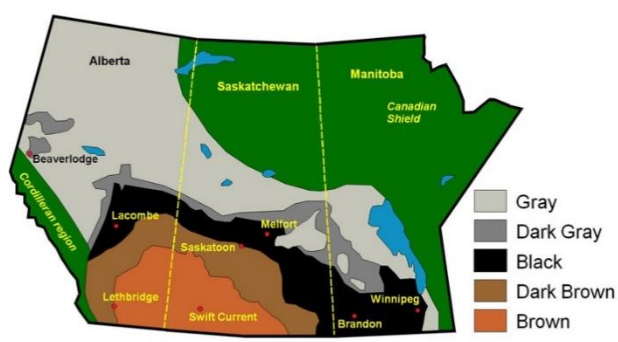


Figure 2. Major Soil Zones of Western Canada

Soil and plant nutrition is a difficult science as every nutrient is somewhat connected. For a plant to be efficient and have an opportunity to express its potential there must be a balance of nutrients (Wikipedia n.d.). Mulders Chart (below) illustrates how each nutrient is related and shows that one in excess can negatively affect another that is assumed to be sufficient.

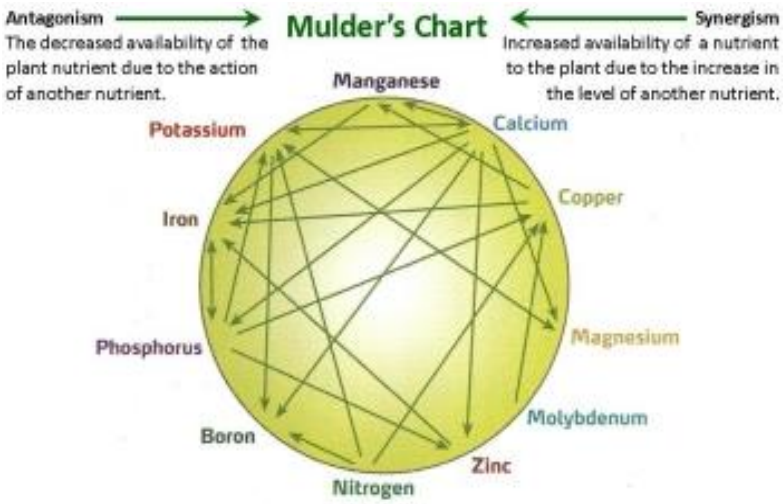


Figure 3. Mulders Chart showing the relationship and interaction between nutrients

For most plants, a pH range of 5.5-7.0 is considered optimal for growth. Some plants have adapted and excel at differing pH ranges. As the soil pH decreases, the chance for aluminum, hydrogen and manganese toxicity increases. Soil pH is not an indication of fertility, but it does affect the availability of soil nutrients. The following pH chart shows how nutrient uptake is affected. Most of the elements are quite accessible between 6-8 pH. Phosphorous, for example, becomes less available in more acidic environments while copper and zinc are limited in alkaline environments.

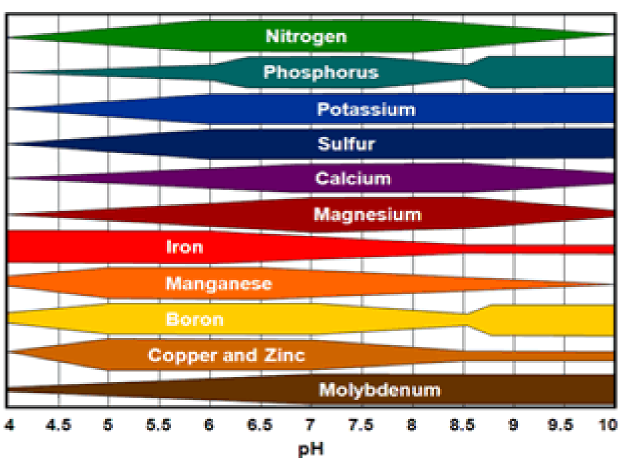


Figure 4. Nutrient availability at given pH levels

Soil biology is defined as *"the study of microbial and faunal activity and ecology in soil. Soil life, soil biota, or soil fauna is a collective term that encompasses all the organisms that spend a significant portion of their life cycle within a soil profile, or at the soil-litter interface"* (Soil Biology n.d.). The biology within the soil is a key driver in decomposition of organic matter, influencer in soil fertility, plant growth, soil structure, and carbon storage. For example, bacteria aid in nitrification, nitrogen fixation, and sulfur conversion. Beneficial fungi such as mycorrhizae form a symbiotic relationship with plant roots to extend and enhance the exploration of nutrients and water. Larger fauna such as earthworms can aerate and stir the soil to increase soil stability and water infiltration.

Soil organic matter (SOM) is a component of soil comprised of plant and animal residues at various stages of decomposition. SOM is a very important characteristic that defines the quality of a soil and is quite often an indicator of overall potential productivity. It is a large sink for carbon and nutrient turnover in the soil as it decomposes to form humus. Humus differs from SOM as humus is the stable fraction that has no identifiable plant or animal characteristics.

2.1.1 Soil Sampling

A soil sample is a key tool in determining the composition of your soil, including physical, chemical, and biological. Aside from the fertility levels, it can determine the organic matter and carbon levels, texture, pH, bulk density, cation exchange capacity (CEC), biological quality and activity in the soil. These attributes all have an effect on the availability of nutrients in the soil and influence plant growth. A soil with high or low pH has a very distinct effect on phosphorous availability and can directly affect the amount needed.

The depth of the sample also needs to be taken into account. Mobile nutrients such as nitrogen and sulfur can leach into a lower depth of soil and still be within the rooting zone of a plant. Conversely, less mobile nutrients such as phosphorous, potassium, and copper may be stratified in a shallow top layer (especially in a no-till practice). In this case, if a 0-30 cm sample is taken, it may not give an accurate concentration of stratified nutrients and may not be deep enough to show what nutrients are at depth. Without adequate sampling depth(s), strategic fertilization plans may be difficult to implement.

Soil sampling sites should be planned and plotted prior to sampling. The inclusion of different tools such as yield maps, Normalized Difference Vegetation Index maps (NDVI), Electrical Conductivity maps (EC), topography maps, and long term experience can aid in choosing soil sampling sites. They can determine high or low producing areas that need to be treated differently, identify different soil types, and ultimately aid in determining application of soil amendments, overall fertility or potential land use.

There are many different styles and strategies pertaining to soil sampling as well as the laboratory analysis. Similar depth, timing, and handling in conjunction with the use of GPS and the same laboratory analysis will provide some key fertility and soil attribute trends over time. These trends may include soil fertility levels, organic matter and carbon levels and soil chemical attributes.

Some experts believe that soil sampling should be done every year. Since every agriculture business is different, I suggest answering two questions first: what am I testing for and what will I do with the information? After taking this and the sampling budget into consideration, some may decide to sample only a certain portion each year.

Why is soil sampling so important? A soil sample is like a blood sample. It can provide some important clues to what's happening beneath the surface. In Western Canada, most view a soil sample as a prescription for nutrients with nitrogen being the major one. Different areas of the world have different goals. Some areas do not test for nitrogen because they believe it will all be used or lost to leaching, volatilization and/or runoff. Some use soil testing for pH and lime application purposes first and a nutrient test second because pH is the limiting factor.

2.1.2 Determining Soil Quality and Characteristics

As previously mentioned, there are tools available to help understand soil characteristics and locate sample points on a quantitative basis.

A yield map may be the first step in determining the overall performance of a field or paddock. When the harvester is calibrated correctly, the data it collects can be downloaded and transformed into a visual tool to help make important decisions. This can be used in a very simple way to pick sample points directly or can be integrated with other technology.

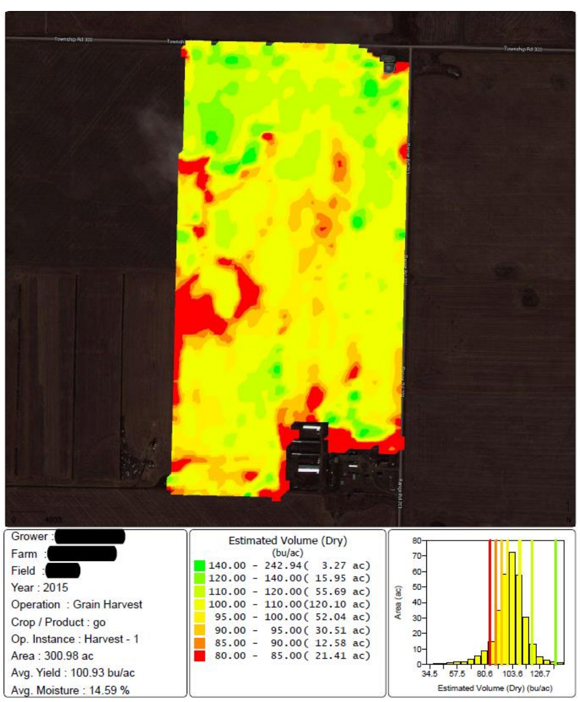
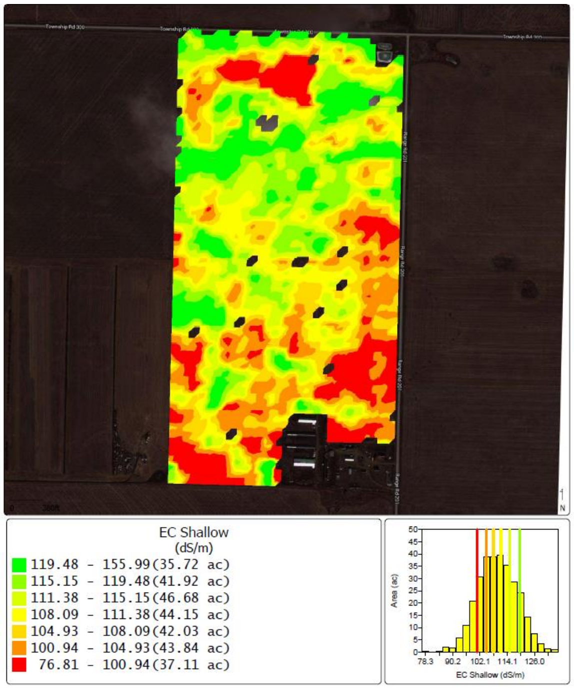
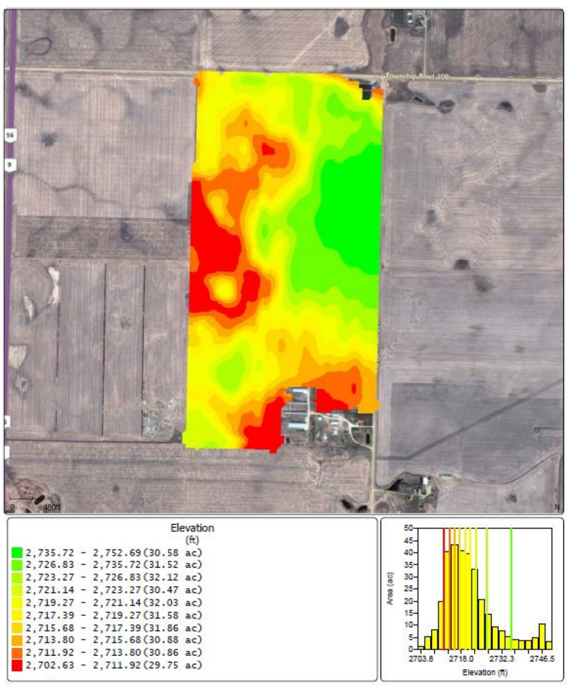


Figure 5. Yield Map (Red= lower yields, Green= higher yields)



Mapping the soil's EC measures how easily an electrical current passes though the soil. It can indicate the differing amounts of sand, silt, clay, organic matter and water content. It can also indicate areas of salinity. All of these are contributing factors to soil productivity. When an EC value is high, it indicates that the amount of clay particles is higher than the sand particles. When it is lower, the amount of clay is reduced.

Figure 6. Electric Conductivity (EC) Map (Red= low EC, Green= higher EC)



A topography map can pinpoint peaks, valleys, and midslopes. Although it may not directly depict different soil types, it can help explain why vegetation densities and yields are different in certain areas. They can also be used for determining application sites for soil amendments or drainage plans.

Figure 7. Topography Map (Red= lower elevation, Green = higher elevation)

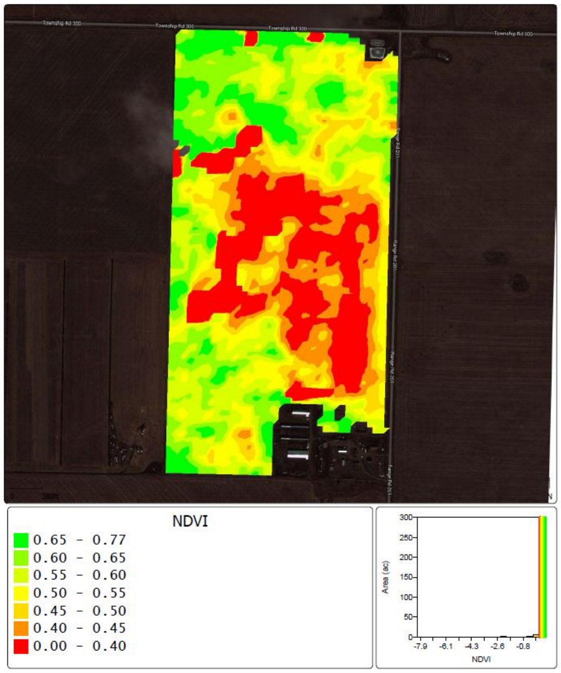


Figure 8. NDVI Map (Red= low reflectance, Green= higher reflectance)

Normalized Differential Vegetation Index (NDVI) is an index of a plant's photosynthetic activity. It is based on the principle that different surfaces reflect different types of light. Photosynthetic plants absorb most of the red light and reflect much of the near infrared light. There has been much research on how NDVI can direct us to more productive areas and create long term vegetation maps. NDVI does have its limitations because it is not a direct measure of soil quality, but rather a measure of "greenness" produced by the ratio of infrared and red light that is reflected from the surface.

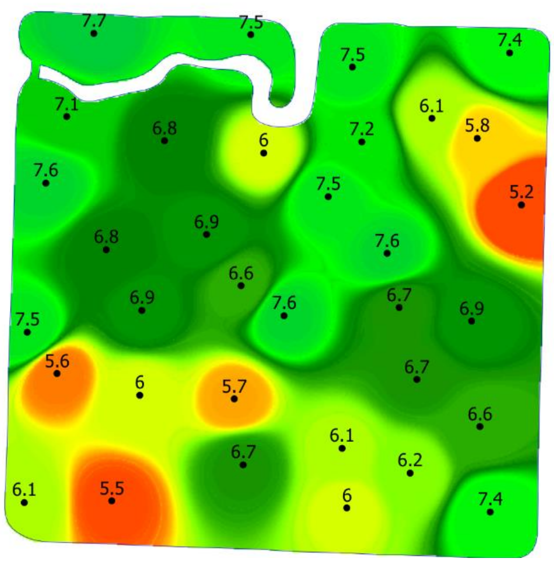


Figure 9. 5 acre grid sample showing pH values

Grid Sampling is as simple as setting up a grid of a field or paddock and sampling accordingly. Grid size may vary depending on the size of the field, but could represent anything from several square meters to a 10 acre grid. It can help determine soil zones for application of variable rate lime or nutrient applications.

Though technology is a great way to produce a quantitative measure for an area, good old fashioned experience cannot be forgotten. Someone may remember where a fence line was 60 years ago, where the old manure pile was spread or where an old yard site was. Maybe that part of the field was grass and pasture for many years and the rest was not. The list is endless, but a combination of all tools can be very useful.

2.2 Increasing Diversity to Improve Soil Quality

A common theme that I noticed in my studies is that there are more farming businesses selling off and exiting livestock than there are entering. Farms seem to be more specialized and are growing in size at the expense of diversity. This may be a problem, as the most successful operations have diversified to withstand economic and agronomic peaks and valleys.

Diversity can have a very different meaning to different individuals. Diversity in agriculture ventures consisting of grain, forage, pasture and livestock production can vary and ultimately improve one's soil and in turn, their financials. Adding diversity is not a scientific decision; it should be based on what best fits your and your business. Keep in mind that a current system with little diversity will respond to subtle changes the quickest. If the operation is already quite diverse and has implemented changes, new changes may be more difficult to measure and analyse.

I am going to discuss several different operations that I had a chance to visit. They all have increased diversity in their soils and businesses that resulted in changes to soil quality and ultimately resulted in an economic benefit.

Trevor Syme farms northwest of Perth, Western Australia (WA). Some of his soils are considered to be non-wetting sands, which do not allow water to infiltrate because of parent material and gradual buildup of plant waxes. I had a chance to witness clay spreading in action, considered to be a remedy of non-wetting sands and a way to improve structure and infiltration. The concept of this procedure is to spread a subsoil clay material (typically dug from borrow pits in the same paddock) in a thin layer roughly 25mm thick on the surface (250 tonne/hectare). The subsoil clay is located by using an EM38 machine, which measures soil EC. This clay is then mixed with the topsoil which improves soil composition and allows rainfall to infiltrate into the soil rather than running off and/or evaporating.

Trevor also deals with acidic topsoil and requires lime to increase the pH, but these subsoil clays typically have a higher pH which results in a lesser need for lime. The direct cost of claying these non-wetting sands is costly at $1000/hectare, but the benefits are justified. His yields have been measured at 2-5 times greater in comparison to the check where no clay was spread.

Figure 10. Clay spreading in Western Australia

Andrew Fowler of Chatham Farms operates a grain and stock farm near Esperance, WA. They have a very efficient and diverse operation with 28,000 ha, 25,000 ewes and 2,500 mother cows. They carry all the steers and heifers to 18 months of age and then sell direct to market. Andrew has developed a direct to market system that works for his farm because of their scale and the genetics used in the cattle. 18,500 ha is in a cropping rotation that includes canola, wheat, silage, and pasture.

Pasture, in their terms, is uncropped land that allows any plant to grow and is utilized for grazing. They have a subterranean clover that is indigenous to the area and grows naturally. It is a legume that sets seed below ground and is therefore quite tolerant to high intensity grazing. This allows them to use high stocking rates as weather and growth allow.

They also graze wheat and canola during the month of July with no yield penalty or delay of harvest. Stocking densities are matched to growth rates so that the plant is not injured. They are finding that grazed canola just prior to flowering can increase yield as compared to ungrazed canola because the plant is shorter and has less disease risk.

Andrew said "in grain production, we have done all the easy things and the next steps are very technical and expensive." On their farm, pH and compaction are some of their major concerns. They have utilized EC mapping to help determine where to spread gypsum, lime, and clay but also rely on personal knowledge and a simple Google map image. They realize that pH is continually declining because they test their soil every three years prior to canola planting and have been tracking trends. They want to address this issue before it becomes a major problem that is expensive to correct. Controlled traffic is being implemented but it does take time and capital to purchase or modify equipment as needed.

I was very impressed with Andrew and his family's farm. It may have been one of the most interesting grain/stock farms that I had visited primarily because they harvest an indigenous recurring legume and graze cropland at a specific time with no grain yield penalty. He has realized that introduction of stock has enabled growth and feels it is better for the soil as compared to growing any legume. He is approaching technology carefully and admits he needs to research it further in order to help his farm.

David Cox of Waterhatch Farms also operates a grain and stock farm near Esperance, WA with focus on soil biodiversity with the use of crops, perennial forage, stock and technology. The utilization of cattle has allowed him to convert land that is prone to saturation into grazing lands by planting winter barley and rye grass. This has increased his stocking densities four times as compared to the area average. The use of drought tolerant grasses and tagasaste has allowed David to utilize land that is too sandy for arable farming. Tagasaste is a leguminous shrub that provides grazing for stock and a nitrogen source to the grass growing around the shrubs.

For David's annual crops, he utilizes N Rich strips to assess how much nitrogen is needed to produce the highest possible yield. This system only looks at nitrogen as the limiting factor in fertility recommendations because of spatial variability and differing environments from year to year. He spreads nitrogen early on in the crop's life cycle and then measures at tillering with sensors such as a Greenseeker to determine his in-season nitrogen application. To combat his non-wetting sand and pH issues, he has reintroduced a mechanical operation using a moldboard plough. Although it is very unconventional, he is able to bury hard to kill and chemical resistant weed seeds, bury the top thatch layer to promote deeper rooting and water infiltration, and bring deeper clays to the surface to slightly increase his pH and improve soil structure without intensive clay spreading and mixing operations. He does admit that this is not applicable to every soil or environment, but he has taken some risks and it seems to work for him. He then follows up on these lands with controlled traffic to limit further compaction.

Figure 111. Established forage on soils prone to water saturation (left), tagasaste and grass established on sandy and erodible land (Right)

Figure 12. Soil ploughed 10-15 cm deep with the black thatch layer buried

Figure 13. Canola roots 1 year after the soil was ploughed (left) vs no-till soil (right)

In the UK, Steve Townsend of Soil First Farming has been an advocate for improving soil health by reducing tillage and incorporating cover crops. In many parts of the UK, the plough is the norm and many are not convinced that no-till is needed. His approach is quite simple, with a focus on soil management, fertility management and keeping the soil "alive" with active plant growth for as long as possible.

Soil management takes into account biological, physical, and chemical aspects. Each aspect is equally as important. Fertility needs to be matched to the crop and the correct timing. The correct form is as crucial as the timing so the plant can actually access the nutrient. Steve utilizes the Albrecht Theory for fertility which encompasses the balance of soil chemistry including the macro and micro elements. The introduction of a cover crop after harvest can keep the biological portion of the soil alive. Soil biology depends on respiring plants as much as a plant depends on soil biology aiding in mineralization, water infiltration, and aeration.

Steve's approach to a cover cropping system that includes no-till is simple:

1. Grow simple crops that are cheap and have plenty of root growth to loosen the soil. Such crops may include mustards, linseed, oats, and rye (year 1-3).
2. Grow crops with lots of biomass such as sunflower (year 4-6).
3. Grow crops to promote biodiversity such as legumes (year 7-9).

This system will not show improvements in a short period of time; it will take years. He sees improvements such as less compaction, well aerated soils, greater rooting depth, greater water infiltration, and increased fertilizer efficiencies.

Figure 14. Steve Townsend in a field of Winter Rapeseed assessing soil compaction and rooting

Sander Bernaerts of Naturim, Netherlands is a consultant to organic farmers and those that are transitioning into organics. Organics in Netherlands is quite small in comparison to their $70+ billion overall agriculture trade, but it is growing very fast as the demand is steadily increasing. Sander introduced me to the fertility view of organics. Our discussion was primarily around field crops such as set onions, potatoes, vegetables and wheat. Although fertility was the main discussion, he was quick to point out that he felt soil structure was a limiting factor and getting worse. Without the use of chemical weed control, mechanical control is necessary and is contributing to a breakdown of soil structure.

When farmers are transitioning to organic production, Sander advocates the use of cover crops such as grass clover. Grass clover provides several benefits including diversity in the rotation, soil structure regeneration, and a source of cattle fodder. He sees a real value in cover crops as a way to help reduce soil erosion and increase soil organic matter.

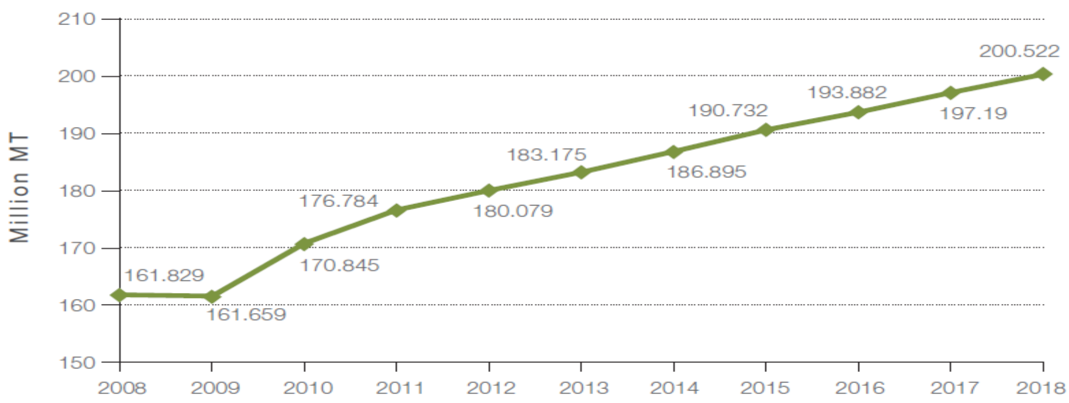
The organic sector still needs to replace nutrients, no different than a farm using chemical fertilizer. In addition to having some of the most productive soils in the world, they have a resource very close to them - livestock manure. There are a number of sources including swine, dairy and poultry. Sander typically monitors the nitrogen and potassium levels in the soil so that they do not over apply according to the rules set by the European Union. When added nitrogen is needed vetches and legumes will be used in a cover crop situation.

2.3 Increasing Nutrient Efficiencies

The intent of my global research was to investigate how we in Western Canada could become more efficient with our fertilizer applications and use. Since the adoption of no-till, there has been extensive research on best management practices for application and different forms of fertilizer nutrients. Since many of our farms are becoming larger and more specialized, the equipment has grown and efficiencies have become very important and sometimes supersede basic agronomy. I did not find the direct answer I was looking for in my research, but I did find many pieces of a puzzle that could help everyone increase nutrient use efficiencies.

According to the Food and Agriculture Organization of the United Nations (FAO), the usage of global fertilizer nutrients (specifically nitrogen, phosphorous, and potassium) are expected to increase steadily at a rate of 1.8% until 2018 (World fertilizer trends and outlook to 2018 n.d.). The biggest increase in usage will be potassium, followed by phosphorous in emerging areas such as Eastern Europe, parts of Asia and Africa. In North America our consumption will steadily increase but not to the extent of other countries. Should we continue to apply these nutrients and not utilize them, or can we take some steps to effectively use what is applied?

Graph 1. Global nutrient ($N+P_2O5+K_2O$) consumption and projected needs to 2018 (World fertilizer trends and outlook to 2018 n.d.)



2.3.1 Soil Microbial Populations

Promoting and increasing the growth of microbial population in the soil can aid in the search and extraction of immobile nutrients such as phosphorous and potassium. Arbuscular mycorrhizal fungi (AMF) formation, as one of many examples, changes several aspects of plant physiology and some nutritional and physical properties of the soil rhizosphere. AMF is a fungus that penetrates the root cells of vascular plants and then extends its rooting network to help capture valuable nutrients and water. AMF has the ability to affect 80% of the flowering plants on earth (Jos´e-Miguel Barea, Rosario Azc´on, Concepci´on Azc´on-Aguilar 2002). AMF has been used to increase nitrogen fixation of rhizobia bacteria in dry conditions and increase phosphorous uptake in low phosphorous fertile soils. AMF may be less prominent in high or excessive phosphorous soils (Chantal Hamel, Désiré-Georges Strullu 2006). Rhizobia infection of pulse crops is a very well-known symbiotic interaction of bacteria and plant roots to fix atmospheric nitrogen. Pulse crops are high users of nitrogen and are great protein sources for many human cultures and animal feeds. Again, in high nitrogen fertility soils, this infection may be slower occurring because the plant will utilize the mineralized nitrogen in the soil prior to fixing atmospheric nitrogen.

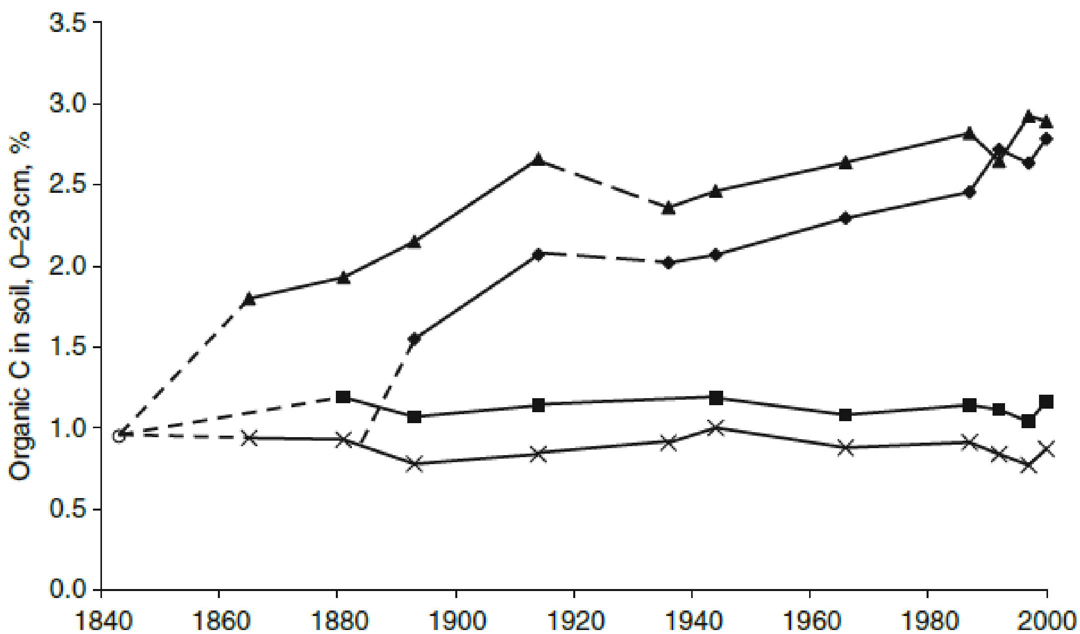
In both cases, a well-managed system can help utilize the applied fertilizer. Encouragement of a fungus or bacteria colonization in highly fertile soils may not be useful because the plant will have the ability to explore and satisfy its own fertility needs. In moderate to low fertility levels, colonization will help added nutrients to be captured and used before they are lost or tied up in soil solution.

2.3.2 Soil Organic Matter

Soil Organic Matter (SOM) has a very complex set of properties which makes it difficult to quantify its effects. As it breaks down, it has the ability to release nitrogen, phosphorous, potassium, sulphur, and trace elements, stabilize soil structure on poor soils, increase cation exchange capacity (CEC) of the soil, and increase soil water holding capacity and available water. It has been difficult for scientists to mimic these attributes in the lab using chemical fertilizers only. Increasing SOM is not easy and takes a very long time. One of the long-term studies at Rothamsted Research showed that it took in excess of 120 years to raise the SOM 2-3 times using farm yard manure as compared to using chemical fertilizer alone (A. Edward Johnston, Paul R. Poulton, Kevin Coleman 2009).

SOM can greatly affect the soil quality by providing a constant breakdown and plant available nutrients. However, the breakdown rate is different in soils depending on physical, chemical, and biological properties. SOM is a like a bank account; without constant additions such as residue or manure, the account balance slowly disappears. This may not be the answer for reduction of fertilizer additions, but it could be a tool to rely on when conditions are favorable for increasing production without adding in-season chemical fertilizer.

Graph 2. Changes in percent organic carbon (%C) in the top 23 cm of a silty clay loam soil, Boardbalk Winter Wheat experiment, Rothamsted. Annual treatments: unmanured since 1844, ***X****; P,K,Mg plus 144 kg N/ ha since 1852,*■ *;* *35 t/ ha Farm Yard Manure* since 1844, ▲; 35 t/ha Farm Yard Manure since 1885 plus 96 kg N/ha since 1968 ⧫ *(A. Edward Johnston, Paul R. Poulton, Kevin Coleman 2009)*



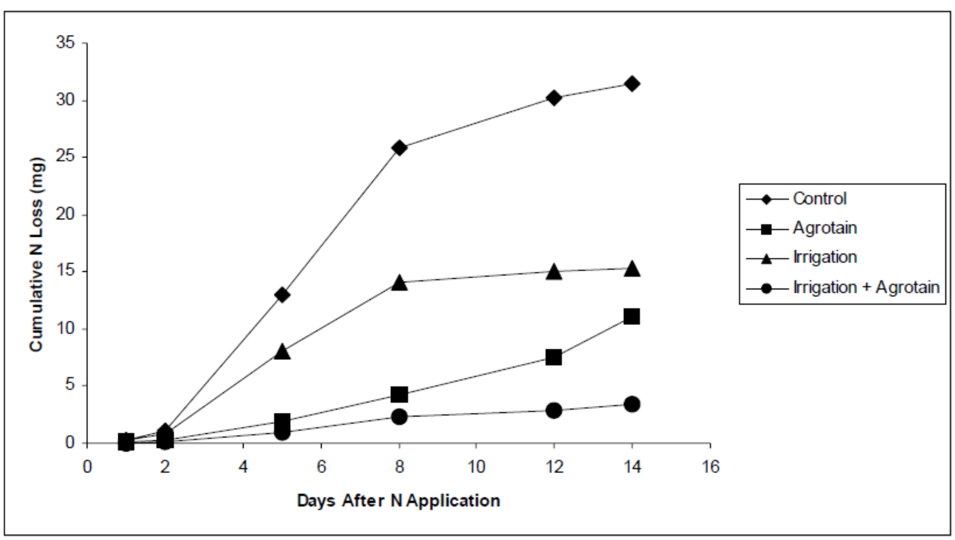
2.3.3 Enhanced Efficiency Fertilizers

Enhanced Efficiency Fertilizers (EEF) are fertilizer products that can reduce nutrient losses to the environment while increasing nutrient availability for the plant or the crop. These fertilizers can either slow the release of nutrients for uptake or alter the conversion process of nutrients to be less susceptible to loss. Such EEFs include controlled release nitrogen fertilizers, nitrogen stabilizers and phosphate management products. A return from these products should not be expected every year, but EEFs should still be considered as a risk management tool.

Controlled release nitrogen fertilizers typically come in two forms: sulfur coated urea and polymer coated urea. The idea for both systems is to control the amount and rate of water entering and solution exiting. The purpose of these products is to limit environmental losses (leaching, denitrification, and volatilization), control the release of nitrogen for constant feeding of the crop and to increase seed safety when nitrogen is placed with or close to the seed. Different soil types, rainfall accumulation, timing for uptake, etc. have all been studied. These products can reduce environmental loss, but may not be economically feasible or practical in all production systems.

Nitrogen stabilizers are used to slow the activity of urease enzymes that are necessary for urea based fertilizers to hydrolyze and convert to plant available nitrogen. They are reliant on temperature and moisture to determine the breakdown rate. These products can be useful when urea based fertilizers are surface applied to reduce volatilization until adequate moisture has been received to carry it into soil solution. They can also be used when high rates of nitrogen fertilizer are required and placed in close proximity to the seed as the concentration of NH_4 can be reduced and improve seedling safety.

Graph 3. Volatilization loss from surface application of urea as affected by application of Agrotain, with and without addition of 2.0 cm of water on day 4 and day 7. (C.A. Grant, C.D.L. Rawluk n.d.)



Phosphorous use efficiencies still have a long way to go. Only 5-25% of applied P_2O_5 in a year is actually taken up by the plant, with higher amounts accumulated in low phosphorous fertility soils (Curtis J. Ransom, Micheal W. Hill, and Bryan G. Hopkins 2011). The remaining is then tied up in the soil solution and bound by ions such as aluminum, calcium, magnesium, and iron which are also pH dependent. There are several fertilizer additives ranging from chemical to microbial that can help improve P_2O_5 uptake. One of these products forms a negatively charged barrier around the positively charged phosphorous molecule so that negatively charged molecules such as calcium and magnesium cannot form tight cohesive bonds and render the phosphorous unavailable to plants (Simplot n.d.).

When EEFs are being used or tested, the nutrient must be adjusted so that toxicity or deficiency does not occur. For example, if using an EEF with phosphate, a reduction in application may be needed so that phosphorous toxicity does not occur and cause a micronutrient deficiency. If a polymer coated urea is being used for a nitrogen source, then there may not be sufficient nitrogen available at critical plant stages. Therefore, when different fertility systems are being implemented, all nutrients and their relationships need to be recognized and application rates adjusted accordingly.

2.3.4 Rooting and Compaction

Roots are the primary driver of a plant's ability to capture nutrients and water. When soil nitrate levels are high, root biomass and root: shoot ratio decrease, more roots are found in the shallow topsoil layer and root growth is depressed. When a larger portion of root biomass is located deep in the soil, the plant can maintain greater transpiration rates (Kemo Jin, Jianbo Shen, Rhys W. Ashton, Rodger P. White, Ian C. Dodd, Martin A. J. Parry, William R. Whalley 2015). Fertilizer efficiency is not only based on the source of fertilizer, but also on the ability to influence the plant to increase its root and shoot mass so it can root deeper to search for moisture and nutrients.

Soil compaction can have many negative effects on a plant's ability to access nutrients and water. Compaction can restrict root growth, root mass, soil bulk density, water infiltration and biological activity. If the relationship between roots, soil, and nutrients is unable to exist because of compaction, increased efficiencies of applied nutrients will not occur. Root impedance is directly correlated with leaf elongation and the photosynthetic rate of the plant (Kemo Jin, Jianbo Shen, Rhys W. Ashton, Rodger P. White, Ian C. Dodd, Martin A. J. Parry, William R. Whalley 2015). There are ways to mitigate compaction including the use of tramlines, controlled traffic farming, deep rooting crops and rotations including forages and cover crops.

2.3.5 Plant Growth Regulators

Plant Growth Regulators (PGRs) are a chemical compound that is applied to plants to impact hormonal activity in order to beneficially modify the plant's growth and development. PGRs are typically used to reduce the height of a plant which results in reduced lodging, increased tillering and increased yields. Many parts of the world have been using PGRs for a long time, but they are relatively new to Western Canada and are being studied to see if they are economically beneficial. Application timing of these products is critical, as there can be detrimental effects if not applied correctly.

PGRs help the plant to be more efficient if lodging is nil or minimal. Lodging can cause losses of up to 80% depending on severity and the stage of the plant's life cycle (Caierao 2006). Increased fertility levels may lead to lodging. The overall result of lodging is a reduction of expected yield and reduced nutrient efficiency which is ultimately a waste of money.

2.3.6 Nutrient Application and Form

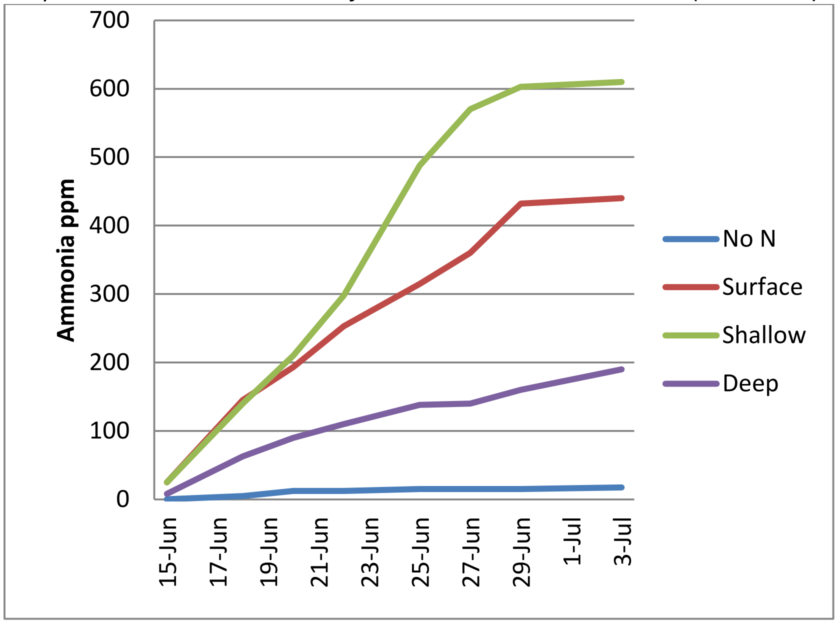
In Western Canada there has been a lot of research of nutrient placement specific to our climate and agronomy practices. Throughout my travels, research, and personal experiences, I asked questions based on what we have been taught over the last 30 years with the adoption of no-till and direct seeding. This section will ask more questions and inspire conversation rather than provide definite answers.

Graph 4 is only a short term study but asks an interesting question. It shows the potential ammonia loss is greater in shallow placed (less than 3 inches or 7.6 cm) urea fertilizers than compared to surface application (Heard n.d.). Several factors that may contribute to this outcome include:

1. The overall fertility of the soil or the amount of ammonia already present is high. The more concentrated ammonia is at or near the surface, the greater the chance for loss.
2. Soil pH drives potential ammonia loss. The higher the pH, the greater the risk of loss.
3. Moisture condition of the soil. Moist soil below and a dry surface will initiate hydrolysis and initiate the conversion of urea into ammonia.

Deeper application of urea fertilizers can reduce ammonia losses but there are other factors that need to be considered such as efficiency of time, equipment, and fuel consumption. Using EEFs to protect nitrogen losses, as previously discussed (2.3.3), are a great risk management tool when considering a surface application.

Graph 4. Relative ammonia loss from side-dressed UAN in 2012 (Heard n.d.)



What about surface applying our phosphorous and potassium needs if erosion is not an issue? Very little phosphorous is used in the year of application (5-25%) and the remainder is supplied by the soil solution. What is the harm in surface application, providing it is not physically removed and does not end up in our water shed systems? There would still be benefit to having a small amount with or near the seed to provide the "pop up" effect. With the higher amount of phosphorous that is required, there are some seedling safety concerns that may be overlooked.

While in Germany, I was able to discuss a nitrogen application method called CULTAN (Controlled Uptake Long Term Ammonium Nutrition). Its basis is a one-time injection (per season) of liquid fertilizer containing as much ammonium nitrogen as possible into highly concentrated pockets or "depots" at a depth of 6-10 cm. The ammonium ion is very stable in these depots because in the internal parts, the concentration of nutrients for the activity of nitrification bacteria is too high. By fertilization through CULTAN method, the ammonium nitrogen is received only in the roots, which have grown up to the edge of the depot which hinders the phytotoxic effect of ammonia. These roots sprout intensively and concentrate round the depot's edge. During the plant's vegetative growth period, the roots move from the outer edge of the depot inwards (KubeSova, J. Ballk, O. Sedlar and L. Peklov n.d.). CULTAN fertilization allows for a more precise application and a more uniform distribution of the fertilizer. This method allows for the application of nitrogen regardless of field conditions (wet or muddy) and reduces soil compaction. Specialized equipment is needed to inject fertilizer and is more costly than spraying or broadcasting.

Figure 15. A CULTAN fertilizer applicator observed in Germany

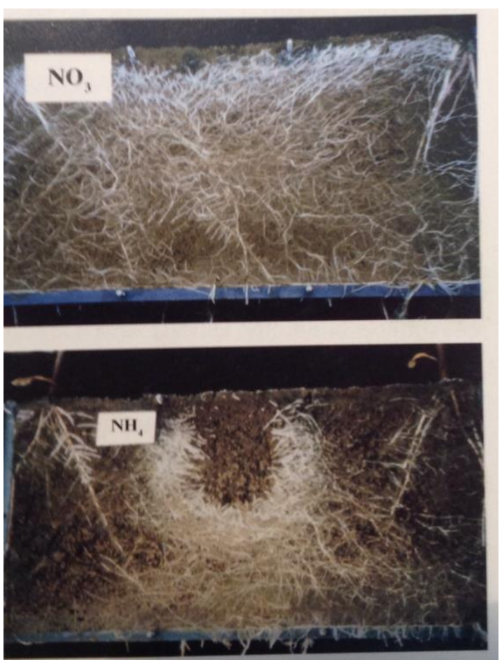


Figure 16. The difference in rooting between NO_3 and the NH_4 rich depot from CULTAN (KubeSova, J. Ballk, O. Sedlar and L. Peklov n.d.)

There are increasing questions regarding different liquid and granular products. In Western Canada, most of our dry fertilizers are derived from mono-ammonium phosphate (MAP), which is ortho-P and plant available. Liquid fertilizers are derived from a variety of sources including blends of ortho-P and poly-P (unavailable form) and complete ortho-P blends. Poly-P needs to be converted into ortho-P and is dependent on temperature, pH, soil microbes, and soil type. Conversion can occur in 4- 100 days, so product choice and placement is very important. Different applications of liquid vs. dry ortho-P must be considered because of distribution, efficiency and salt index. Liquid forms, when applied correctly, can increase the frequency of distribution and overall efficiency while decreasing salt index.

Most research suggests that there is no significant difference between using granular or liquid phosphorous or a combination there of. Water solubility of the most commonly used phosphorous sources is very high and does not restrict the availability of the added fertilizer. An argument for distribution could be made if sufficient rates are used. However, research conducted by companies marketing liquid starter phosphorous have shown some long-term gains on yield. In Eastern Canada, there are reports of an average increase of 3.2 bushel per acre in corn over 23 years and 3 bushel per acre increases in winter wheat over 13 years (Alpine Plant Foods n.d.). The information provided for Western Canada is showing similar results in the short term.

Sulphur is typically required in the early stages of the crop lifecycle, so having the correct form of sulphur available to the crop is important. The release from organic matter is quite small (2-3 lbs/% organic matter) and typically happens later in the growing season. Without adequate fertilization sulphur demanding crops could become deficient especially on sandy and low organic matter soils.

Application of high rates of elemental sulphur has become an increasing trend in Western Canada. If applied correctly to allow sufficient time to oxidize and be broken down by Thiobacillus bacteria, there will be enough plant available sulphur for high demanding crops such as canola. If the product is broadcast, 25-35% return can be expected in year one while the remaining 65-75% will become available over the next 3-4 years.

The added benefit is that there will be continual breakdown during the growing season and several following seasons to help succeeding crops. Elemental sulphur is not subject to volatilization or leaching, but it can be prone to erosion. Although this strategy can help nutrient, plant, equipment, and labor efficiencies, it is an investment in the land with amortization over 3-4 years. If this is applied to leased lands, the farmer may be at risk of losing his or her investment.

2.4 Introduction and Incorporation of Technology

The options available to farmers are nearly endless and more are coming to market steadily. It can be overwhelming, but everyone does not need to implement everything on their farm. For those that are just starting to incorporate Precision Agriculture (PA), keep it simple. PA is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. SEPWA (South East Wheat Growers Association) located in Esperance, Western Australia are working with their members to incorporate PA at a simple and affordable level. They are teaching them how to identify variability in their paddocks and create application maps for fertilizer, lime and clay spreading applications.

Climate Corporation based in San Francisco, California "aims to build a digitized world where every farmer is able to optimize and flawlessly execute every decision on the farm". They are developing a platform that will combine local weather monitoring and simulation along with agronomic modelling to help farmers become more profitable by making informed operating and financial decisions. The agronomic modelling data comes from farmers and includes, but is not limited to SOM levels, temperature, moisture, germ plasm, fertility, nutrient use, elevation, planting information, etc. The complexity of this model is hard to fathom, but it will help farmers to decide what genetics best suit them, when to apply fertilizer, estimate harvest dates and estimate yields. It is currently only available in the USA for use with corn, but it will be available in other areas and for other crops as more data is collected.

In order for PA to be effective, a farmer needs to have collected data on his or her <u>own</u> farm. As discussed in 2.1.2, these sampling and data collection techniques may be the foundation of incorporating PA. These options are relatively easy to find and purchase. Current harvesters usually have the ability to capture yield data that can be downloaded and converted to a usable form. Improvements can be made by collecting data and knowing your farm at an intimate level, but one must be careful not to drown themselves with data. Is there such a thing as having too much data? Perhaps the first question that needs to be asked is "What am I prepared to do with this data?"

3.0 CONCLUSION

In my travels, I saw many different soils ranging from deep volcanic soils on the slopes of Mount Kenya where they can grow a wide range of crops compared to Western Canada at elevations around 2500 meters above sea level. I also saw weathered, saline and acidic soils in Western Australia where cost of productions is one of the most important decision making tools they use. Highly eroded soils in the USA's Midwest and the inclusion of cover cropping is reducing the amount of soil, pesticides and fertilizers that are being deposited into streams, rivers, lakes and the ocean.

Figure 17. Kisima Farms planting field peas on the north slopes of Mount Kenya in Kenya

Figure 18. Excavator clearing drainage canals for saline ground water in Western Australia

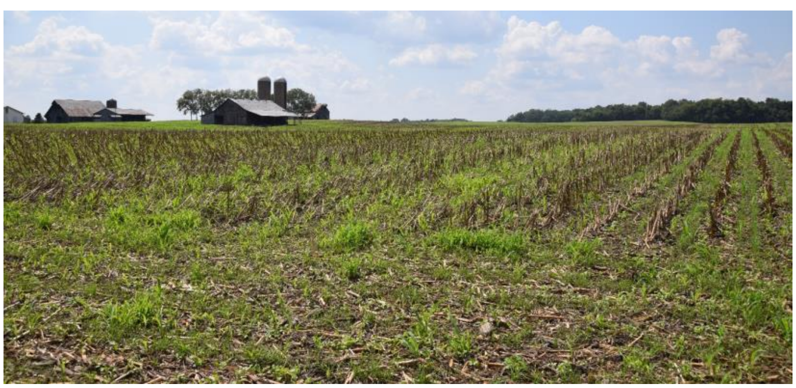


Figure 19. Cover crop establishment after corn harvest in Kentucky, United States

It didn't take me very long to realise that we have some very good soils in Western Canada, but we may be exploiting a natural resource that will be very difficult to fix. Western Canadian soils have only been cultivated for roughly 100 years. They are in decent shape as of today, but years of wind erosion and ploughing of our topsoil has reduced our bulk densities and organic matter levels. With the adoption of no-till in the last 30 years we have halted the decline, but we are operating large and heavy equipment that is further reducing bulk density, increasing compaction and reducing the deep rooting abilities of cultivated plants.

Managing soil is a process and the incorporation of forages, pasture, or cover crops can help remedy our damaged soils. If we promote the living part of the soil so that it can survive, flourish, capture carbon, and add diversity to our systems by using a combination of crop rotation, forages (perennial and/or annual), and livestock, we may be able to leave the soil in an improved condition.

4.0 RECOMMENDATIONS

My research has been primarily focused on grain production. After coming home and reflecting on all that I have learned, I realize that grain production is a part of a larger system. It is common knowledge that monocultures are not sustainable for long periods of time. Broad acre agriculture that is practiced in Western Canada may need to consider something more than cereal grain and canola production. Many have incorporated legumes into a rotation but this will not give the yield increase that is required to feed the increasing global population.

I believe all farmers have passion for what they do. Most have preferences and focus more on grain or livestock, but it all revolves around soil. Whatever the preference is, there is opportunity to change and improve, even just a little bit. Throughout my research, I compiled ideas and recommendations for farmers. Although my focus is in Western Canada, portions may be applied globally.

Think about your soil first! Soil is a living medium that allows agriculture to exist. Soils rely on photosynthetic and respiring plants to stay alive and plants need a healthy, living soil to flourish. Without one, there will not be the other. Soil has an amazing buffering capacity and is able to somewhat repair itself if not constantly being disturbed. We can help this process by encouraging continual plant growth where ever possible by using a cover crop, forages, or pastures. This will have a direct impact on the soil and its ability to live, capture carbon and improve in quality. Trying to improve soil quality takes time, effort and a plan so direct results may not be seen immediately.

Incorporate and utilize data and technology. This does not need to be difficult or encompass everything. Utilize what is available and applicable to your business. There are people offering services to help incorporate, implement, and analyse the data to help turn information into profit. Those profits may not be realized immediately, but choosing and incorporating your options wisely will pay off.

Profit drives investment! Where should those profits be reinvested? Land? Infrastructure? Equipment? Each farmer knows what is best for their own business, but many will not think about direct investment in soil. Such investments could include soil testing, soil amendments, or physical manipulation of the soil. Businesses may decide to reinvest in diversifying a portion of the farm into livestock, hay production or trees to completely change the system.

“Without change, nothing changes”. Systems need change and most people are scared of it. Mother Nature is always changing and always will, therefore if agriculture systems do not change and adapt with her, we do not know what the outcome may be. Change should likely start in lower potential fields, paddocks or pastures because improvements will be seen quicker as compared to higher potential areas. Find out why the area is poor. It may a number of reasons including soil limiting characteristics such as salinity or pH issues in areas. Low fertility may limit production depending on what the target plant is to be grown. Soil or air borne pests may be present such as fungal root rots or insects impeding the root or foliage growth. Ensure the correct crop or forage has been chosen for the correct environment. Conditions may not be correct for the variety or species of plant that is trying to grow. A topography assessment may need to be completed due to poor drainage or eroded knolls. The list is endless, but decisions need to be based on what is best for the agriculture system that is implemented and it will be different for every system. There is no manual written for these decisions or practices but consider failures as a positive step forward. The only wrong answer is doing nothing.

My study, “Management Techniques for Increasing Plant and Nutrient Efficiency to Improve Food Production” made me realize that continual yield increase and an increase in global food supply will not be a simple, one-step approach. I uncovered and conclude that it will be a systems approach with particular attention to soil. The ideas discussed throughout all have a direct impact on the soil and its ability to improve. The following are the main points that I discussed and could be incorporated into a system:

1. Invest in soils by utilizing different testing methods and incorporating technology to improve soil structure and organic matter
2. Increase the diversity of the farm. Incorporate livestock, legumes, forages, and/or pastures to promote soil biology. Inclusion of crops to fix atmospheric nitrogen or promote the growth of mycorrhizal fungi to extend the plants ability to search for water and nutrients.
3. Implementation of cover crops to encourage soil biology to be active for longer periods of time which will help in residue management and nutrient turnover.
4. Consider the 4R’s of nutrient stewardship; source, rate, time and place. Including enhance efficiency fertilizers can potentially further reduce nutrient loss and increase nutrient use efficiency.
5. Incorporate deep rooting crops to help in the repair of soil compaction, improve soil bulk density and water infiltration.

5.0 GLOSSARY

Diffusion: the net movement of molecules or atoms from a region of high concentration to a region of low concentration

No-Till: (also called zero tillage or direct drilling) is a way of growing crops or pasture from year to year without disturbing the soil through tillage

N Rich Strips: an additional strip of N fertilizer is applied across the paddock. This strip need only be a combine or air seeder width (solids) or a boom spray (fluid), and the rate can be 50 to 100 kg N/ha, and maybe 100 to 300 m long - it depends on the variability of the soil in the paddock and the sort of information the grower wants - site specific or general.

Soil buffering capacity: is the ability of the soil to stop nutrient or pH changes by absorption. For soils, it is the capability of absorbing nutrients and also releasing them (cation exchange capacity). Hemic acids and clay minerals have good buffer qualities.

Soil organic Matter: component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms.

Soil rhizosphere: the narrow region of soil that is directly influenced by root secretions and associated soil microorganisms

Symbiotic: refers to any diverse organisms that live together, but in this case, the relationship is not necessarily beneficial to both

Vascular plants: plants that have the vascular tissues xylem and phloem. The vascular plants include all seed-bearing plants (the gymnosperms and angiosperms) and the pteridophytes (including the ferns, lycophytes, and horsetails).

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